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Effects of different dosages of caffeine administration on wrestling performance during a simulated tournament

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Abstract

The aim of the present study was to investigate the effects of different forms of caffeine administration on physical performance during a simulated wrestling tournament. In a double-blind and randomized experiment, twelve male freestyle wrestlers competed in a simulated wrestling tournament (5 wrestling matches consisting of 2×3-min wrestling rounds) following the ingestion of: a placebo, a high-dose of caffeine (10 mg/kg), a moderate-dose caffeine (4 mg/kg), a repeated-dose caffeine (2 mg/kg before each match to a total of 10 mg/kg) or a selective caffeine administration based on performance decrement previously measured (6.16±1.58 mg/kg). The Pittsburgh Wrestling Performance Test (PWPT) was measured before each match to assess physical performance. In comparison to the placebo, the high dose of caffeine only reduced PWPT time before the first match (56.8±2.0 vs. 52.9±1.8 s; $p < 0.05$). The moderate dose of caffeine did not affect PWPT performance during the tournament. Both, the repeated dose and the selective administration of caffeine reduced PWPT time with respect to the placebo in the third (66.7±1.8 vs. 63.1±1.4 s; $p < 0.05$) and fourth matches (72.3±2.4 vs. 65.9±1.3 s; $p < 0.05$). However, only the selective dose of caffeine reduced PWPT time before the fifth match (62.7±3.0 vs. 56.3±2.0; $p < 0.05$). The dosage and administration of caffeine affect the ergogenic effects obtained following the ingestion of this substance. An individualized protocol to provide caffeine when physical performance is expected to be reduced might improve wrestling performance during the latter stages of a tournament.

Keywords: *Competition, Performance, Coaching, Recovery.*

Introduction

Wrestling is a combat sport that was practiced in the Ancient Greek Olympics Games and is also one of the most important combat sports that have inclusion in the Modern Olympic Games (Barbas et al., 2011; Demirkan, Koz, Kutlu, & Favre, 2015). Wrestling consists of a physical fight between two opponents of similar body mass with the purpose of gaining and maintaining a superior position over the rival. The fight includes grappling-type techniques such as clinch fighting, throws, takedowns, joint locks, pins and other grappling positions with the final aim of throwing and pinning the rival to the matted area (Chaabene et al., 2017). Greco-Roman style wrestlers are only allowed to use their upper-body during the fight and holds below the waist are forbidden. However, the freestyle modality permits the use of the whole body during the fight (Chaabene et al., 2017). A wrestling match consists of two 3-min rounds which include short periods of high-intensity efforts interspersed with brief periods of rest or moderate-intensity work to allow recovery for the next bout (Barbas et al., 2011). Specifically, the short bursts of maximal intensity observed during the fight are mainly maintained by anaerobic metabolic pathways which include anaerobic glycolysis while the primary role of the aerobic system is to aid in the recovery process within and between successive matches (Rezasoltani, Ahmadi, Nehzate-Khoshroh, Forohideh, & Ylinen, 2005; Terbizan & Seljevold, 1996). All these characteristics indicate the necessity of possessing highly developed capacities of maximal strength, power, endurance and anaerobic capabilities in elite wrestlers.

Wrestling tournaments are one-day or two-day events, with three to five matches per day, depending on the success of a wrestler throughout the progressive rounds. For instance, the winner of the 2017 World Wrestling Championships had to fight five matches in a single day (United World Wrestling, 2017). However, what makes wrestling more physiologically demanding and challenging is the short recovery (from 30 min to 3 hours) allowed between the matches (Barbas et al., 2011; Chaabene et al., 2017). A few previous studies investigating the physiological profiles in wrestling tournaments have shown that the succession of matches during the tournament induces significant increases in the ratings of fatigue and decreases in muscular power and strength (Barbas et al., 2011; Kafkas et al., 2016; Kraemer et al., 2001). This suggests an incomplete recovery between matches that produces a progressive decline in physical performance ability for the remaining tournament duration.

An interesting question is how wrestlers can achieve a faster physiological recovery to return to the required level of fitness prior to the next match. Legal ergogenic aids with properties to increase performance and/or to accelerate recovery between matches may be of benefit to improve the athletes' recovery profile. The ergogenic effect observed may also enhance the athlete's chance of overall tournament success. Caffeine seems a promising substance to provide benefits during multi-match events such as a wrestling tournament. Caffeine has been previously reported as being beneficial in other sports comprising various competitions in the same day (Del Coso et al., 2013; Diaz-Lara, Del Coso, Portillo, et al., 2016; Santos et al., 2014). Specifically, caffeine administration seems to improve several physiological parameters that are specifically related to wrestling performance. These include, muscle power, strength, agility, vigilance, attention and reaction time (Aedma, Timpmann, & Oopik, 2013; Astorino & Roberson, 2010; Spriet, 2014). Although the scientific literature is scarce, previous work on combat sport demonstrated that caffeine ingestion (3 to 5 mg/kg) might improve reaction time and delay fatigue during successive taekwondo combats (Santos et al., 2014) or the time spent in offensive actions during a Brazilian jiu-jitsu competition (Diaz-Lara, Del Coso, Portillo, et al., 2016). However, although a higher glycolytic contribution has been detected with the acute ingestion of caffeine (5 mg/kg), other investigations have failed to detect improvements in overall performance during a simulated taekwondo or judo competitions (João Paulo Lopes-Silva et al., 2015; Saldanha, Kons, & Detanico, 2018). Lastly, the unique study with mimiced wrestling matches found that acute caffeine ingestion (5 mg/kg) had a partially detrimental effect on upper body intermittent sprint performance in trained wrestlers (Aedma et al., 2013). It should be noted, however, that the simulated competition consisted of four 6-min upper body intermittent sprint performance tests with 30-min recovery periods, which may not entirely represent a real wrestling tournament.

In an attempt to advance the knowledge regarding the efficacy of caffeine ingestion to increase wrestling performance, we designed a research protocol to determine which form of caffeine administration is more beneficial to maintain physical performance during a simulated one-day wrestling tournament. Moreover, because caffeine ingestion may be associated with dehydration and gastrointestinal complaints (Spriet, 2014), we also investigated which methodological approach resulted in lower prevalence of side effects while maximizing performance.

Material and methods

Participants

From an initial sample of 41 volunteers, 12 wrestlers were recruited (age: 24±3 years, body mass: 75.8±4.0 kg, and body mass index: 24.1±1.8 kg/m^2). The inclusion criteria consisted of the following: wrestlers to be professional male freestyle, wrestling experience of at least 10 years, age between 20 to 28 years, non-smoker, and no current musculoskeletal problems. All wrestlers were screened by a physician prior to participating in the study. All participants indicated that they consumed less than 3 cups of coffee per day, and as a result were considered as low-to-moderate caffeine consumers. Wrestlers were familiarized with testing devices and procedures prior to experimental data collection. All subjects were informed about the benefits and risks of the study prior to providing their written informed consent. The study was approved by the University Institutional Review Board.

Study Design

The study was performed 2 weeks after completing the in-season wrestling period. This ensured that the athletes were fully recovered from the effects of prior competitions and that they all reported for testing with maximal levels of physical fitness restored. During these two post-season weeks, routine exercise sessions mainly consisted of technical and tactical tasks. Body mass and height (287, Seca, Germany) were taken two days before the first experimental session to allow individualized caffeine dosages. Participants were encouraged to maintain their routine lifestyle regarding nutrition and exercise, and sleep habits during the study. The day before each experimental trial, participants refrained from strenuous exercise and adopted a similar diet and fluid intake regimen, replicating their pre-competition routines. Moreover, participants were encouraged to withdraw from all dietary sources of caffeine (coffee, chocolate, cola drinks, etc.) for 48 hours before testing. Diet, fluid ingestion, and sleep patterns were recorded using self-report questionnaires before the first trial and replicated in subsequent trials.

All participants undertook 5 experimental trials with 5 days between each trial to facilitate washout and recovery. In a double-blinded manner, participants ingested: a placebo, a high-dose of caffeine (10 mg/kg), a moderate-dose of caffeine (4 mg/kg), a repeated-dose caffeine (5 × 2 mg/kg), and selective caffeine consumption protocol based on the expected physical performance decrement previously measured (6.16±1.58 mg/kg; see below). Because this last one must be based on performance decrement, the placebo condition was performed initially and the values obtained used as a reference to calculate the decrement in performance for subsequent trials. Then, using a counterbalanced and crossover design, participants performed the remaining experimental sessions with caffeine.

In each experimental trial, participants competed in a simulated wrestling tournament following the rules of the International Federation of Associated Wrestling Styles (FILA). This was used to improve the ecological validity of the outcome measures. Participants performed five matches; each match consisted of 2×3 min rounds of competitive wrestling with 30 s of passive rest between the rounds. As in a real wrestling tournament, the second, third, and fourth wrestling matches were performed 45 min after the previous match, while the last match was performed after 3 h after of recovery (Figure 1). To standardize all procedures, all the trials included the 5 times of ingestion, one 45 min before the first match (that included the full dose of caffeine for 10 and 4 mg/kg trials) and the remaining four (that included caffeine or placebo) ~30 min before the following matches. Caffeine (Oriola OY, Finland) was always co-ingested with a drink containing Sprite® and cherry syrup to mask the taste of caffeine.

Of note, the selective caffeine supplementation was innovative because it was designed to individually provide caffeine when physical performance decreases. For this protocol, one week before the first experimental trial, participants performed 10 Pittsburgh Wrestling Performance Test (PWPT) with 30-min rest between bouts. For each participant, the mean and the standard deviation (SD) of PWPTs were calculated and performance declination was defined as having an increase in PWPT time longer than 1 SD. Thus, during the experimental trial with the selective caffeine supplementation, caffeine (2 mg/kg for each time) was provided when PWPT time increased 1 SD from baseline. In this experimental trial, no athlete was provided with caffeine before the first match, but 7/12 athletes were provided with 2 mg/kg before the second match, 9/12 athletes received caffeine before the third match, 12/12 athletes received caffeine before the fourth match and 9/12 athletes before the final match. The average caffeine intake in this trial was 6.16±1.58 mg/kg with one wrestler consuming caffeine twice in the protocol (4 mg/kg) and another wrestler receiving a maximal dose of 8 mg/kg.

Physical performance measurements

The PWPT was performed 6 times in each experimental trial: in the baseline measurement (20 min before the first intake of caffeine/placebo; Figure 1) and 5 min before each match, as part of the athlete's warm-up protocol. The PWPT was always performed as described previously (Utter, 2001). For this measurement, wrestlers were paired with an opponent of the same weight category who did not participate in the study. The test consisted of a series of 5 special wrestling moves with 5 repetitions including double-leg and single-leg takedown, stomach-to-back lift, fireman's carry and hip toss (Utter, 2001). The partner was completely inactive during the test and did not move any opposition or consent. After each move, the inactive wrestler came back to the standing position until the active wrestler completed the 5-repetition set. During the test, the participant was asked to perform the test with the same intensity, speed and technique as during a real match. Wrestling performance was evaluated based on the PWPT time to the nearest 1.0 s using two stopwatches (Delta E200, Switzerland). Maximal hip/back strength and jump height were measured during baseline measurement and immediately before and after each match. Hip/back strength was measured using a dynamometer (Takei Digital Dynamometer, UK) as previously described (Barbas et al., 2011; Kraemer et al., 2001) while the maximal vertical jump height was measured using an infrared beam system (Just Jump System, Probotics, USA). The best score in three attempts for each of these two tests was used for statistical analysis.

Heart rate, fatigue and blood lactate concentration

Heart rate, perceived fatigue ratings and blood lactate concentration were measured during baseline measurement and immediately before and after each match. Heart rate was monitored in a seated position by a standard Monark belt (Vansbro, Dalarna, Sweden) for 1 min. Fatigue rating was obtained using 0-10 a Likert scale, as previously described (Barbas et al., 2011; Kraemer et al., 2001). Wrestlers reported feeling of fatigue, with zero score being “no fatigue” and 10 “severe fatigue”. Blood lactate concentrations were measured from fingertip blood samples using a portable analyzer (Lactate Pro, Arkray KDK, Japan). The order of measurements before and after each match were standardized that first, heart rate, then blood lactate and fatigue and following these measures, hip/back strength and vertical jump were evaluated.

Hydration Status and gastrointestinal complaints

A urine sample was obtained from each participant during baseline measurement and post final wrestling match, to indirectly assess hydration status in each experimental trial. Urine volume was determined by a graduated cylinder, urine specific gravity was measured using a refractometer (RHB-90ATC, Brix, Hongkong) while urine osmolality was calculated by an advanced osmometer (A20, Hettich Benelux, Netherlands). Dehydration index was determined based on four dehydration scores including urine color, osmolality, specific gravity and creatinine excretion (Armstrong et al., 2010; Hahn & Waldreus, 2013). In addition, gastrointestinal complaints were determined by a questionnaire at the end of the experimental trials (Felippe, Lopes-Silva, Bertuzzi, McGinley, & Lima-Silva, 2016). The gastrointestinal complaints questionnaire consisted of 11 items which each item having a score between 1 and 10, where 1 shows "no problem", and 10 is "the worst case".

Statistical Analysis

SPSS21 software (IBM, USA) was used for statistical analysis. Initially, the normality in the data distribution was checked with the Shapiro-Wilk test for each variable. The effect of the different forms of caffeine administration on variables measured in each experimental trial was assessed using a two-way repeated-measures analysis of variance (condition × time). The effect of the different caffeine forms of administration on urine osmolality and urine specific gravity was assessed using analysis of covariance. Furthermore, the effects of the different caffeine forms of administration on gastrointestinal complaints, urine volume and dehydration index were measured using a one-way analysis of variance. When violations to the assumptions of sphericity were observed in analysis of variance or covariance, the degrees of freedom were corrected using Greenhouse-Geisser corrections. The partial Eta squared (ηp^2) was used as effect size in analysis of variance and analysis of covariance tests. Bonferroni post hoc tests were applied when necessary. Statistical significance was set at $p < 0.05$. Values are expressed as mean ± SD for the study sample.

Results

Physical performance measurements

The times employed to complete the PWPT in each experimental trial are presented in Figure 2. From similar baseline values, PWPT time progressively increased until the fourth match ($p < 0.05$) and then declined before the final match ($p < 0.05$) in all experimental trials (ηp^2 for time effect: 0.86). Before the first match, PWPT time was lower with the ingestion of the high-dose of caffeine in comparison to all the other trials ($p < 0.05$, ηp^2: 0.1 to 0.13), although this effect disappeared in the following matches (ηp^2: 0.04 to 0.06). Both, the repeated dose of caffeine and the selective administration of caffeine reduced PWPT times before the third and fourth matches when compared to all the other trials ($p < 0.05$, ηp^2: 0.1 to 0.26 and ηp^2: 0.1 to 0.49, respectively). However, only the selective dose of caffeine reduced PWPT time before the fifth match ($p < 0.05$, ηp^2: 0.26 to 0.39). Although there was a significant time effect for hip/back strength and vertical jump height ($p < 0.05$; supplemental data, ηp^2: 0.13 and 0.09, respectively), there was no significant effect on these variables with any of the administration protocols of caffeine.

Heart rate, fatigue and blood lactate concentration

Heart rate increased in all matches in all conditions, but pre-match value in the second match was higher with the high dose of caffeine compared to the remaining trials ($p < 0.05$; Table 1). After the third match, heart rate was higher with the medium dose of caffeine and the repeated administration in comparison to all other conditions ($p < 0.05$), while after the fifth match, heart rate was significantly lower with the selective administration of caffeine ($p < 0.05$). Fatigue rating increased until the fourth match and then decreased in the fifth match relative to the previous match. Wrestlers indicated that they were less fatigued before the fourth match with the repeated and selective administration of caffeine ($p < 0.05$) while participants reported higher levels of fatigue with the placebo before the third and final matches ($p < 0.05$). Regarding blood lactate concentration, this variable presented higher values after the third match with the repeated and selective administration of caffeine ($p < 0.05$). Before the fourth match, blood lactate concentration was lower with the selective administration of caffeine and higher with the repeated administration ($p < 0.05$) in comparison to the remaining trials. Interestingly, blood lactate concentration was higher with the selective administration of caffeine after the fourth and fifth matches ($p < 0.05$).

Hydration Status and gastrointestinal complaints

Urine osmolality and urine specific gravity did not differ among experimental trials and remained unchanged across the tournament (Table 2). However, the urine volume and dehydration index were higher with the administration of the high dose of caffeine when compared to all other conditions ($p < 0.05$, ηp^2: 0.08 and 0.17, respectively). The administration of the placebo and the selective dose of caffeine condition showed lower dehydration index after the tournament when compared to all the other conditions ($p < 0.05$). The scores of gastrointestinal complaints and gastrointestinal discomfort were significantly higher with the high dose of caffeine and the repeated dose of caffeine compared to all the experimental trials ($p < 0.05$, ηp^2: 0.23).

Discussion

To our knowledge, this is the first study investigating the effect of several forms of caffeine administration on physical performance, hydration status, and gastrointestinal discomfort during a simulated one-day wrestling tournament. For this purpose, 4 protocols of caffeine administration, which combined varied doses (from 4 to 10 mg of caffeine per kg of body mass) and timing of ingestion (pre-competition, repeated doses and expected performance decline) were compared to the ingestion of a placebo in professional wrestlers competing in 5 simulated matches. In all experimental trials, overall wrestling performance, measured by means of PWPT, was progressively impaired from the first to the fourth match. Due to the larger rest time between the fourth and fifth matches, performance was then partially regained in the fifth match, but it was still worse than the first match. This indicates that the fourth match is the competition moment when the wrestler faces the highest performance decrement, highlighting the importance of this match to guarantee presence in the final round.

In this regard, the performance in the PWPT improved before the third and fourth matches with the repeated administration of caffeine before each combat (5×2 mg/kg) and with the selective administration of caffeine, which was individually provided when the wrestler' physical performance diminished before the combat (6.16 ± 1.58 mg/kg). In addition, these two protocols of progressive delivery of caffeine also reduced pre-match ratings of fatigue before the fourth match. Interestingly, only the selective administration of caffeine was capable of improving PWPT before the final match (Figure 2). On the other hand, the administration of a high dose of caffeine (i.e. 10 mg/kg) before the onset of the competition improved PWPT performance before the first match but also produced the largest gastrointestinal and hydration disturbances during the tournament. Together, these results suggest that individual supplementation of caffeine based on expected performance decrements during the competition might be an effective strategy for those wrestlers seeking to maintain physical performance in the fourth and final matches of a wrestling competition.

There is an ample body of evidence demonstrating that caffeine might positively affect physical performance in various disciplines (Astorino & Roberson, 2010; Dolan, Witherbee, Peterson, & Kerksick, 2017; Shearer & Graham, 2014; Spriet, 2014; Trexler, Smith-Ryan, Roelofs, Hirsch, & Mock, 2016) and accordingly, this substance is widely used in most sports (Del Coso, Munoz, & Munoz-Guerra, 2011); however, some studies have not reported positive effects of caffeine on performance during combat sports (João Paulo Lopes-Silva et al., 2015; Saldanha et al., 2018). Collectively, the information about the possible ergogenic effects of caffeine on combat sport is scarce and even contradictory. Astley et al. found that 4 mg/kg of caffeine ingestion improved performance in judo-specific testing along with a significant reduction in perceived exertion (Astley, Souza, & Polito, 2017) but Lopez-Silva et al. determined that 6 mg/kg of caffeine were ineffective to increase physical performance in judokas undergoing rapid weight loss (J. P. Lopes-Silva, Felippe, Silva-Cavalcante, Bertuzzi, & Lima-Silva, 2014). Diaz-Lara et al. demonstrated that 3 mg/kg of caffeine improved physical performance before and during a simulated competition of Brazilian jiu-jitsu (Diaz-Lara, Del Coso, Garcia, et al., 2016; Diaz-Lara, Del Coso, Portillo, et al., 2016) while Santos et al. showed that caffeine ingestion (5 mg/kg) delayed fatigue during successive taekwondo combats (Santos et al., 2014). Lopez-Silva et al. (2015) and Saldanha et al. (2018) observed a positive metabolic effect (e.g., increased glycolytic contribution to the metabolism during competition) of 5 mg/kg of caffeine that was not translated into any performance benefit during specific testing for combat sports or simulated competitions of taekwondo and judo, respectively. However, the only investigation carried out with caffeine in wrestling indicated that 5 mg/kg was ineffective in increasing performance (Aedma et al., 2013). In the current investigation, the use of a moderate dose of caffeine (4 mg/kg) was investigated along with other forms of acute and repeated caffeine administration. Confirming the investigation of Aedma et al. the moderate dose of caffeine was not enough to increase any of the variables used in this investigation to assess performance (Aedma et al., 2013) (Table 1 and Figure 2). Yet, the acute ingestion of 10 mg/kg was effective to significantly improve PWPT performance before the first match. This suggests that higher doses of caffeine are necessary to produce ergogenic effects in wrestlers. This high-dosing of caffeine before the competition did not produce further benefits during the tournament. Also, the participants reported a higher frequency of gastrointestinal complaints in conjunction with a diminished hydration status (Table 2).

Caffeine is rapidly absorbed within the stomach and small intestine and appears in the blood within 5–15 min of ingestion. However, it takes about ~40 minutes to reach peak values in the plasma (Spriet, 2014). This fast absorption rate of caffeine can produce elevated serum caffeine concentrations when the dose is high and acute, and thus, increase the likelihood of positive performance but also negative gastrointestinal effects. Due to the possible side-effects derived from the acute ingestion of a 10 mg/kg of caffeine, we also investigated the effectiveness of the same absolute dose but divided into 5 timed periods of ingestion (one before each match; i.e., 5 × 2 mg/kg). According to a previous investigation (Conway, Orr, & Stannard, 2003), the division of the caffeine dose can produce a more gradual rise of caffeine in plasma, and therefore a reduction in the prevalence of pernicious side-effects. Interestingly, the repeated dose of caffeine did not affect performance in the first two combats but it increased PWPT performance before the third and fourth matches. This is important because the fourth match was the most fatigable, which imposed a big challenge to the following final match. Furthermore, the repeated dose of caffeine ameliorated the gastrointestinal complaints and reduced the dehydration index at the end of the tournament. Thus, it seems clear that a high dose of caffeine (> 5 mg/kg)(Aedma et al., 2013) is necessary to significantly improve performance during high-level wrestling and the division of the dosage can reduce non-desirable physical and physiological outcomes.

As an innovative approach for the use of caffeine in sports, we designed a method to administer low and repeated doses of caffeine (2 mg/kg) when the wrestlers were experiencing a reduction in physical performance resulting from the succession of matches. This approach gave the wrestlers the opportunity to avoid the use of caffeine before competition but allowed them to administer before the second and the remaining matches. With this protocol, the dose of caffeine used was moderate (6.16±1.58 mg/kg) but produced the maximal performance benefits at the end of the wrestling tournament (Figure 2). It has been recently suggested, only the use of low-to-moderate doses of caffeine can produce the antagonist action of caffeine at A1, A2A and A2B adenosine receptors (Fredholm, Yang, & Wang, 2017). Thus, the use of a moderate dose of caffeine, distributed during a wrestling tournament and specifically administrated when the athlete is experiencing fatigue can be an effective form of caffeine use in elite wrestling. This is important because although the large time recovery (i.e., 180 min) after the fourth match, the fifth match started with some degree of fatigue (recovery was only partial once performance was higher than fourth match, but was lower than the first match). This indicates that performance during the last and decisive match can be improved by an individualized caffeine-ingestion approach.

The experimental design used in this investigation presented several limitations that should be discussed to improve the application of the outcomes presented here. First, in real competitions, wrestlers are typically required to lose body mass to reach the specified weight category. In the current study, we simulated a wrestling tournament without asking the athletes to lose body mass before the simulation. The ergogenic effects of caffeine on voluntarily dehydrated wrestlers should be considered experimentally, as this might limit the benefits of caffeine in combat sports (J. P. Lopes-Silva et al., 2014). Second, the ergogenic effect derived from the acute ingestion of caffeine can be highly variable among individuals. One of the most recurrent sources for the variance on caffeine's ergogenicity has been related to the -163C>A polymorphism of the *CYP1A2* gene. This gene codifies the protein CYP1A2, a drug-metabolizing enzyme with major relevance for caffeine metabolism because it metabolizes caffeine into paraxanthine and other methylxanthines (Cornelis, El-Sohemy, Kabagambe, & Campos, 2006; Womack et al., 2012). It has been recently found that the *CYP1A2* genetic variants might results in different rates of caffeine breakdown, ultimately affecting physical performance (Guest, Corey, Vescovi, & El-Sohemy, 2018; Rahimi, 2018; Womack et al., 2012), although this is not always the case. Therefore, further studies on the ergogenic effects of caffeine should take into account the -163C>A polymorphism to investigate whether this genetic variant can affect the benefits of caffeine on wresting and other combat sports performance. Third, although we tried to produce a motivating atmosphere simulating a real competition, it is likely that the mental determination and motivation of athletes were lower than those observed in a real tournament. Fourth, we measured physical performance before and after the matches but we were unable to obtain reliable information of performance during the execution of the matches. Finally, using other tools and analytical techniques, such as time-motion analysis, could add new insights about the effects of caffeine on the dynamics of wresting combats. Therefore, it is suggested to use this time-motion analysis in future studies on this topic.

In conclusion, a moderate-dose of caffeine (4 mg/kg) ingested before a wrestling tournament was ineffective to increase performance in wrestlers. On the other hand, an acute and high-dose of caffeine (10 mg/kg) increased physical performance before the first match, although this dose produced unwanted effects during the remaining matches of the wrestling tournament. The division of a high-dose of caffeine into several low-doses (5 × 2 mg/kg), taken before each match, was effective in increasing performance in the third and fourth matches. This dosage also reduced the side-effects associated with caffeine intake. However, the approach that provided the greatest benefits to wrestling performance was the use of a moderate dose of caffeine (~ 6 mg/kg) repeatedly administrated in low doses (~ 2 mg/kg). This appeared to be most beneficial when the wrestler was presenting reduced physical performance.

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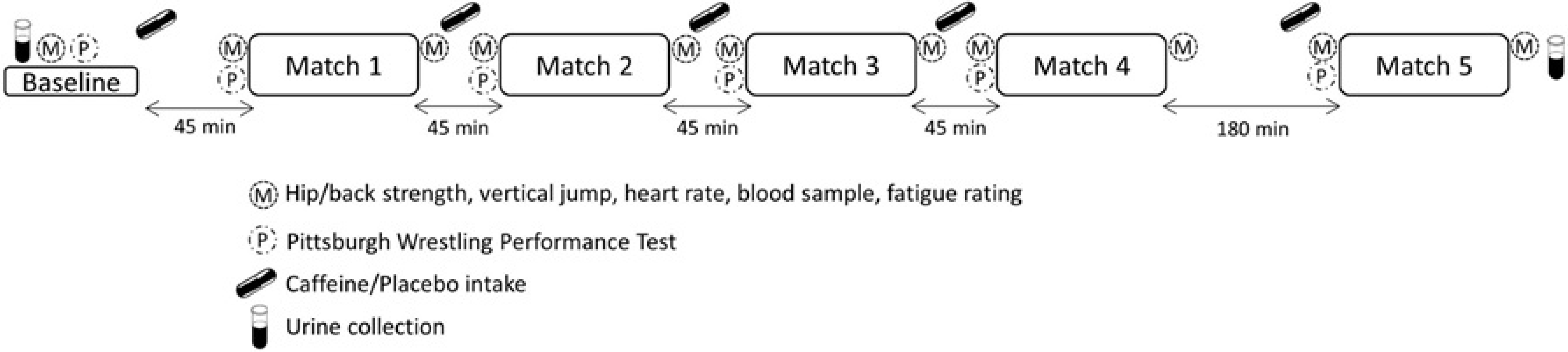
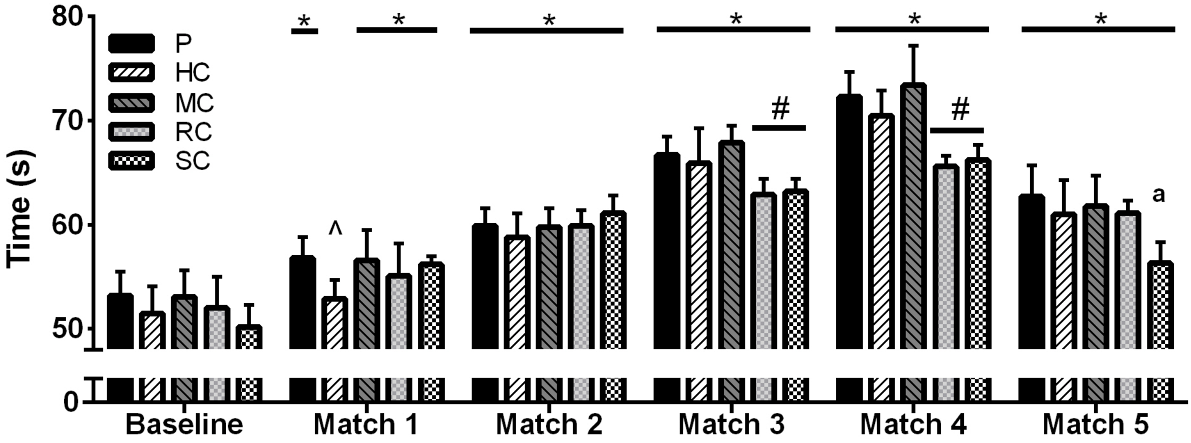

Baseline
Match 1
Match 2
Match 3
Match 4
Match 5
45 min
45 min
45 min
45 min
180 min
Hip/back strength, vertical jump, heart rate, blood sample, fatigue rating
Pittsburgh Wrestling Performance Test
Caffeine/Placebo intake
Urine collection

Figure 1. Experimental design of the investigation. Wrestlers performed a succession of five matches and each match consisted of 2×3 min rounds of competitive wrestling with 30 s of passive rest between the rounds. The second, third, and fourth wrestling matches were performed 45 min after the previous match while the fifth match was performed after 3 h after of recovery. Wrestlers undertook 5 experimental trials: a placebo, a high-dose of caffeine (10 mg/kg), a moderate-dose of caffeine (4 mg/kg), a repeated-dose caffeine (5 × 2 mg/kg), and selective caffeine consumption protocol based on the expected physical performance decrement previously measured (6.16±1.58 mg/kg).



80
70
60
50
0
Time (s)
P
HC
MC
RC
SC
*
#
^
a
Baseline
Match 1
Match 2
Match 3
Match 4
Match 5

Figure 2: Effect of different forms of caffeine ingestion on Pittsburgh wrestling performance test during simulated wrestling competition with 5 matches.

P: placebo, HC: high-dose of caffeine (10 mg/kg), MC: moderate-dose of caffeine (4 mg/kg), RC: repeated-dose of caffeine (5×2 mg/kg), SC: selective-dose (administration of caffeine based on performance decrement; 6.16±1.58 mg/kg).

(*) indicates significant difference compared to baseline at $p < 0.05$

(^) High different to all the other trials at $p < 0.05$.

(#) indicates significant difference compared to Placebo, High and Medium at $p < 0.05$.

([a]) Selective different from all the other trials at $p < 0.05$.

Table I. The effect of different forms of caffeine ingestion on heart rate, fatigue rating and blood lactate concentration during simulated wrestling competition with 5 matches.

		Baseline	Match 1		Match 2		Match 3		Match 4		Match 5	
			Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Heart rate (bpm)	Placebo	72±2	73±2	178±3	73±2	183±3	82±1	183±2	88±1	191±4	80±3	187±3
	High	71±2	73±2	184±3	79±1^	186±3	80±3	183±2	89±4	192±4	81±1	185±2
	Medium	70±3	69±2	181±2	73±2	183±2	78±3	188±1€	86±3	192±4	78±2	187±3
	Repeated	70±1	71±3	173±1	75±3	184±3	79±2	188±3€	83±3€	194±3	83±2	185±2
	Selective	71±3	74±4	182±3	74±3	182±4	84±3	180±4	91±2	190±4	82±3	171±4[a]
Fatigue rating (A.U.)	Placebo	0.0±0.0	0.0±0.0	6.5±0.3	1.2±0.4	7.5±0.5	2.5±0.4	10.1±0.9¥	3.6±0.4	11.6±0.8	3.0±0.6¥	9.9±1.1
	High	0.0±0.0	0.0±0.0	6.1±0.5	1.1±0.5	6.6±0.3	2.1±0.6	7.4±1.1	3.3±0.5	10.4±1.2	1.9±0.7	9.5±1.3
	Medium	0.0±0.0	0.0±0.0	6.3±0.6	1.2±0.3	6.9±0.6	2.4±0.5	7.9±1.3	3.5±0.3	11.5±1.1	2.3±0.6	9.8±1.4
	Repeated	0.0±0.0	0.0±0.0	6.4±0.4	1.3±0.2	6.8±0.4	2.3±0.6	7.2±0.8	2.3±0.4#	10.9±0.6	2.2±0.4	8.9±0.6
	Selective	0.0±0.0	0.0±0.0	6.6±0.4	0.9±0.3	6.9±0.3	2.3±0.7	7.5±0.7	2.2±0.3#	11.1±0.8	2.2±0.3	8.8±0.5

(Table I Continued)

[Lactate] (mmol/L)	Placebo	1.2±0.3	1.4±0.2	15.4±0.6	1.2±0.2	16.3±0.4	2.2±0.3	14.2±0.8	3.2±0.1	12.1±0.9	1.1±0.2	16.9±0.6
	High	1.1±0.1	1.2±0.4	19.3±0.7	1.2±0.1	19.6±0.6	2.1±0.3	14.9±0.6	2.9±0.1	12.3±0.7	1.1±0.6	17.0±0.4
	Medium	0.9±0.2	1.1±0.3	18.5±0.6	1.4±0.2	17.2±0.7	1.6±0.2	13.8±0.5	3.1±0.2	13.4±0.8	1.0±0.4	16.4±0.8
	Repeated	1.1±0.1	1.2±0.2	19.6±0.4	1.3±0.3	19.9±0.7	1.7±0.1	17.0±0.5#	4.2±0.3#	15.9±0.5	1.2±0.2	15.2±0.6
	Selective	1±0.1	1.2±0.1	18.1±0.8	1.1±0.2	16.1±1.1	1.4±0.2	17.3±0.6#	2.1±0.2[a]	17.2±0.3[a]	0.9±0.3	20.1±1.1[a]

(^) High different to all the other trials at $p < 0.05$.

([a]) Selective different from all the other trials at $p < 0.05$.

(¥) Placebo different to all the other conditions at $p < 0.05$.

(€) indicates significant difference compared to placebo, High and Selective at $p < 0.05$.

(#) indicates significant difference compared to placebo, High and Medium at $p < 0.05$.

Supplemental Table I. The effect of different forms of caffeine ingestion on hip/back strength, and vertical jump performance during simulated wrestling competition with 5 matches.

		Baseline	Match 1		Match 2		Match 3		Match 4		Match 5	
			Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Hip/back strength (kg)	Placebo	43.6±3.2	44.0±2.1	43.2±4.0	45.2±4.2	41.2±3.6	40.3±1.6	37.3±3.2	33.3±2.4	26.2±2.7	41.2±2.7	40.2±3.1
	High	42.3±3.4	42.3±2.3	41.3±3.1	41.0±2.6	40.3±1.8	38.2±3.0	36.5±2.7	35.3±2.5	24.6±3.6	40.6±3.2	38.4±3.3
	Medium	42.3±4.4	40.6±3.1	39.7±3.6	42.6±3.4	39.0±3.1	37.4±5.0	34.2±1.9	34.2±2.9	27.6±3.8	39.4±2.9	36.4±3.1
	Repeated	42.2±3.5	41.3±1.6	41.6±4.5	41.2±3.8	38.9±2.6	39.8±3.6	35.6±1.7	35.6±2.6	24.5±5.6	38.9±2.6	37.6±6.6
	Selective	44.2±3.5	45.2±1.7	44.2±3.6	39.6±3.9	37.1±2.1	40.5±3.5	37.2±2.7	35.2±2.2	28.2±4.3	40.6±4.3	38.1±2.5
Vertical jump (cm)	Placebo	42.9±4.1	41.2±3.1	39.2±2.6	42.6±2.4	37.2±2.6	40.9±3.3	36.4±3.2	39.7±2.6	31.0±3.2	37.6±2.5	37.0±2.6
	High	40.2±3.3	40.3±3.9	39.9±2.5	41.8±2.5	35.4±2.5	41.8±3.2	35.2±3.5	38.6±3.1	30.7±2.6	39.4±2.4	38.5±2.4
	Medium	39.8±6.0	44.2±2.8	40.3±3.1	42.3±1.6	35.6±2.4	38.7±2.6	34.7±2.4	37.5±4.2	32.6±2.5	36.1±2.6	36.2±1.6
	Repeated	41.7±3.8	41.2±2.7	41.2±3.2	43.1±2.7	36.1±3.5	39.7±2.9	33.4±2.6	36.9±3.4	30.4±3.4	38.2±3.1	37.6±1.8
	Selective	41.6±4.5	40.1±5.7	38.8±4.3	39.2±2.6	37.9±1.6	40.6±3.3	32.9±1.5	39.0±4.0	32.1±2.4	39.9±2.3	40.1±2.4

Supplemental Table II. The 95% confidence interval (CI) of Pittsburgh wrestling performance test (sec) during simulated wrestling competition with 5 matches.

	Match 1			**Match 2**			**Match 3**			**Match 4**			**Match 5**		
Group	Mean	95% CI		Mean	95% CI		Mean	95% CI		Mean	95% CI		Mean	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Placebo	56.8	55.7	57.9	59.9	58.9	60.9	66.7	65.7	67.7	72.3	70.9	73.7	62.7	61	64.4
High	52.9	51.9	53.9	58.8	57.5	60.1	65.9	64	67.8	70.5	69.1	71.9	61	59.1	62.9
Medium	56.6	55	58.2	59.8	58.8	60.8	67.9	67	68.8	73.4	71.3	75.6	61.8	60.2	63.4
Repeated	55.1	53.4	56.9	59.9	59.1	60.7	62.9	62.1	63.7	65.6	65	66.2	61.1	60.4	61.8
Selective	56.2	55.7	56.7	61.1	60.1	62.1	63.2	62.5	63.9	66.2	65.4	67	56.3	55.2	57.4

Supplemental Table III. The 95% confidence interval (CI) of hydration status during simulated wrestling competition.

	Urine osmolality (mOsm/kg H2O)						Urine specific gravity (A.U.)						Urine volume (mL)			Dehydration Index		
Group	Mean Pre-test	95% CI		Mean Post-test	95% CI		Mean Pre-test	95% CI		Mean Post-test	95% CI		Mean	95% CI		Mean	95%CI	
		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Placebo	590	510	670	623	501	745	1.013	1.009	1.016	1.016	1.013	1.019	425	376	474	2.2	1.6	2.8
High	560	568	652	614	515	713	1.015	1.011	1.018	1.019	1.014	1.023	523	206	300	3.5	3.2	3.8
Medium	571	457	685	600	477	723	1.014	1.011	1.016	1.015	1.009	1.020	434	372	496	2.9	2.2	3.6
Repeated	582	486	678	640	504	776	1.014	1.010	1.017	1.015	1.013	1.017	449	399	499	3.0	2.7	3.3
Selective	596	681	711	620	554	686	1.014	1.009	1.019	1.014	1.011	1.017	442	372	512	2.3	2	2.6

Table II. Hydration status with different forms of caffeine ingestion during simulated wrestling competition with 5 matches.

	Urine osmolality (mOsm/kg H_2O)		Urine specific gravity (A.U.)		Urine volume (mL)	Dehydration Index (A.U.)
	Pre	Post	Pre	Post		
Placebo	590±142	623±216	1.013±0.006	1.016±0.005	425±86	2.2±1.1$^{\$}$
High	560±163	614±175	1.015±0.007	1.019±0.008	523±83^	3.5±0.6^
Medium	571±201	600±217	1.014±0.005	1.015±0.009	434±109	2.9±1.3
Repeated	582±169	640±241	1.014±0.006	1.015±0.004	449±89	3.0±0.5
Selective	596±204	620±117	1.014±0.008	1.014±0.006	442±124	2.3±0.6$^{\$}$

(^) High different to all the other trials at $p < 0.05$.

($^{\$}$) indicates significant difference compared to High, Medium and Repeated at $p < 0.05$.